A FUZZY RULE-BASE MODEL FOR CLASSIFICATION OF SPIROMETRIC FVC GRAPHS IN CHRONICAL OBSTRUCTIVE PULMONARY DISEASES

Umit UNCU[1], Etem KOKLUKAYA[2], Aydin GENCSOY[3], Ovlyaguli ANNADURDIYEW[4]

[1]International Turkmen-Turkish University, Dep.of Computer Eng., Ashgabat, Turkmenistan
[2]Sakarya University, Dep.of Electrical and Electronics Engineering, Adapazari, Turkey
[3]Duzce Devlet ve Travmatoloji Hastanesi (State and Traumatology Hospital), Bolu, Turkey
[4]Turkmen State Medical Institute, Ashgabat, Turkmenistan

Abstract - **In diagnosis of COPD (Chronic Obstructive Pulmonary Diseases), spiromerty is an important "Pulmonary Function Testing" in the medical evaluation of patients. Spirometric measurements FVC & FEV1 are very important to control the treatment, but some difficulties such as incompleteness, inaccuracy and inconsistency are encountered during the test. "Fuzziness in Spirometry" is very important "real-world problem". Even if it is almost impossible to find ideal mathematical equations, ideal prediction formulas and ideal propositions defining the behaviors formulated ideally satisfying the real-life, it is possible to define inexact medical information and findings as fuzzy sets. Furthermore, because of collected data just lying on the border-line cannot be strictly or clearly defined either "normal" or "abnormal", the physicians may misinterpret some criteria or indications. For such kind of reasons, it is needed a formal model of distinguishing COPD group diseases (chronic bronchitis, emphysema and asthma) by using fuzzy theory and to put into practice a "fuzzy rule-base". Purpose of this study is to construct a fuzzy rule-base model for designing a "COPD Diagnosing Fuzzy Expert System by Classifying Spirometric FVC Plots".**

Keywords - **asthma, chronic bronchitis, COPD (Chronic Obstructive Pulmonary Disease), emphysema, expert systems, FVC (forced vital capacity), FEV1, fuzzy logic, knowledge-base, membership function, rule-base, spirometry, VC(vital capacity).**

I. INTRODUCTION

A. Fuzziness in Spirometry

Real-world is characterized by incompleteness, inaccuracy and inconsistency. And there is no need to deal with micro-reasons underlying the events to solve the real life problems as incompleteness, uncertainty and inconsistency. Because, there may not be a solution for the problem, or the approach for the solution may have very complex and time-spending algorithm. As a real life problem, imprecise information is a fact in medical measurement. Problems of incompleteness, uncertainty and inconsistency in medical decision have vital consequences for the patients [1, 2]. Medical data measured or collected about the patient can be characterized according to fuzziness [3]. Additionally, the medical history for the patient may not be objective, i.e. may be exaggerated or ignored [4-6]. A physician may make mistakes or may misinterpret other criteria or indications because the boundary between "normal" and "abnormal" status is not clearly defined, or fail to carry out a complete test for diagnosis [6-8]. Even though the results of the laboratory tests are thought as objective; errors encountered, improper behavior of the patient just before or during the tests can lead to imprecise and incorrect data. Additionally, the measured and collected data just lying on the border-line cannot be strictly or clearly defined either "normal" or "abnormal" [1-3, 11]. Information on medical definitions and evaluations may have incompleteness and uncertainty [1-3]. This kind of medical knowledge is composed of knowledge about the causal relationships, statistics, expert interpretation. Medical relationships depend on time or place and medical approaches and interpretations depend on schools, as well [1-13].

Spirometric FVC & FEV1 measurements are very important to control the treatment [10-19], but some difficulties such as incompleteness, inaccuracy and inconsistency during the test [3-7]. Because of the cases of lack of measurement, patients effort or cooperation during the test, and physicians' interpretations may cause fuzzy data collection [2, 3]. Especially, analyzing data collected or graphs plotted is not easy to categorize, recognize or distinguish for the group of chronic bronchitis, emphysema and asthma because of these reasons [4-7]. Additionally, similar symptoms may cause fuzziness in physicians' interpretations [1-3].

B. Early Studies on Spirometry & Fuzzy Approach

FEV1/FVC ratio is a desirable criteria to define the patient whether he/she has obstruction, restriction both or no problem for his/her lung, FEV1 and FVC tests are the most frequently used pulmonary function tests [12-20]. There are so many useful prediction formulas obtained from pervious studies on spirometry. The "predicted values" for this ratio and prediction formulas have been published [12-15]. The

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Abstract

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TABLE I
VOLUNTEERS CATEGORIZED INTO 8 GROUPS.

Gr. no	Gender	COPD Symptom	Smoking
1	Female	No	No
2	Female	No	Yes
3	Female	Yes	No
4	Female	Yes	Yes
5	Male	No	No
6	Male	No	Yes
7	Male	Yes	No
8	Male	Yes	Yes

use of FEV1/FVC is suggested for determining the presence of "airway obstruction". The value of the ratio is observed by spirometric measurements for discrimination between pulmonary impairment due to restricting cases or airway obstructions can be observed which is the first appear in that study evaluation of the FVC and FEV1/FVC as "normal" or "low", which is a fuzzy theory approach [12, 13]

II. EXPERIMENT

Medical inference is the use of medical knowledge to infer a diagnosis from the symptoms, laboratory results and medical history of the patient. This is complex work with uncertain, exaggerated or ignored, incomplete and inconsistent data [1-3, 9-11].

A. Experimental Setup and Data Collection

For 200 voluntary university students at IBU, in Turkey, spirometric FVC and VC measurements performed in by using a wedge bellow type spirometer [9, 10]. In this study, first of all, for each subject, a questionnaire was filled out before test which is very important criteria for each subject for investigating are smoking cigarettes, having asthma, chronic bronchitis or pneumonia, persistent cough, chest wheezing, having any chest injury and operation, and working in air polluted area for a long time [9, 12]. Secondly, observed FVC and FEV1 data plotted are taken under investigation. According to the questionnaire filled out, subjects categorized in groups [9, 10].

B. Mathematical Modeling and Results

For each FVC plotted by the spirometer for each subject, the best fitted curves and their equations calculated and the coefficients of predicted curves have taken under investigation as fuzzy values [9, 10]. This model, which provides more reliable equation constants for FVC value at t=1 sec. is closer to the observed values rather than the others [9]. After a series of "mathematical modelling" process, it can be found some kind of curve equations which are the best fitted ones and exact values can be calculated by using these equations for FEV1. In mathematical modelling proccess, the

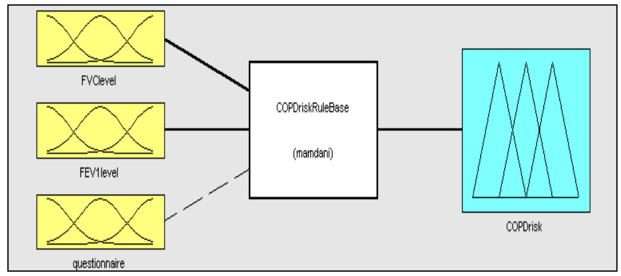

Fig.1. Inference machine with 3-input model

best fitted curve equations and their coefficients investigated with respect to incompleteness for subjects with COPD, compared to the coefficients for healthy subjects to get more reliable constants [9, 11]. For some healthy subjects with the same height and ages, although their predicted FEV1 are the same, relatively big differences for the observed ones, that is defined as "degree of inconsistency" [1-3, 9, 11]. Fuzziness in constants of mathematical expressions derived comes from this inconsistency. This mathematical study summarized as follows [9-11]:

a. This study [9] showed that "fuzzy logic theory" can be used in categorizing the FVC graphs with high levels of confidence [10].
b. The best fitted curves generated for the spirometric plots [9] are highly accurate in order to investigate the relationship between the characteristic coefficients of these curves and the degree of the disease, and the FEV1 values for the subjects under investigation, as well [10].

C. Fuzzificatin of The Best Fitted Curves' Coefficients

Constants for mathematical equations derived for FVC plots for each subject for 8-groups under investigation are fuzzified and normalized for fuzzy labels "VeryLow", "Low", "Normal", "High" and "VeryHigh" for FVC and FEV1

FEV1 \ FVC	Very Low	Low	Normal	High	VeryHigh
Very Low	Very High	Very High	(High) RT	(I) RT	(I) RT
Low	Very High	High	High	(Normal) RT	(I) RT
Normal	(High) RT	High	Normal	Low	(Low) RT
High	(I) RT	(Normal) RT	Low	Low	Very Low
Very High	(I) RT	(I) RT	(Low) RT	Very Low	Very Low

LEGEND: I=Inconsistent, RT=Repeat the Test,

Fig. 2. Rule-Base set for the simulation for this study.

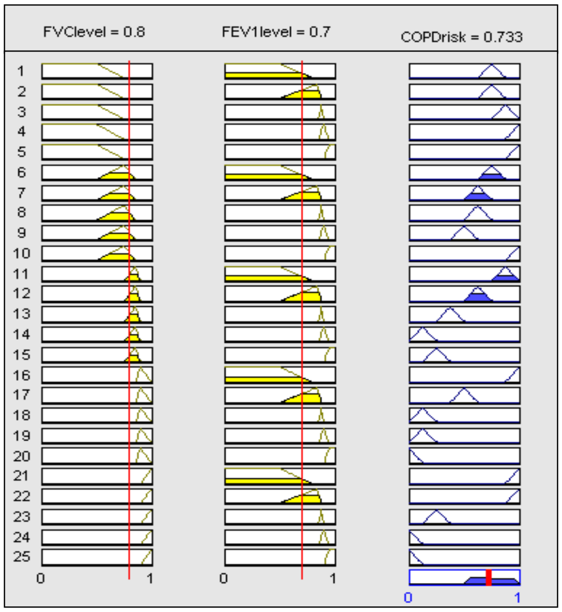

Fig. 3. Simulation: Rule-Base and Mamdami method for inferencing.

levels are shown for each group as shown in the TABLE I [1-3, 8, 9].

D. Generating Rule-Base

Fuzziness in medical information and elimination of complexity between medical relationships and fuzzy information need defuzzification. For medical diagnosis, relationships in theory, expert interpretations, statistics, laboratory and instrumental results must be put together to get rules for defuzzification and then get exact solution. Degree of fuzziness (uncertainty level) of the disease must be defined. The defuzzification needs to generate rules to get exact results using by theoretical, experimental laboratory tests and measurements and expert information. In some fuzzy cases, it is seemed to be in the confidence limits of the normal cases. But, falling below or seeming to fall below the confidence limits of the normal cases misleads the physician to interpret the spirometric results. Also, using the prediction equations and the medical information obtained from patient to be manipulated together may give uncertain, exaggerated or ignored, incomplete and inconsistent results [1-3, 7-11].

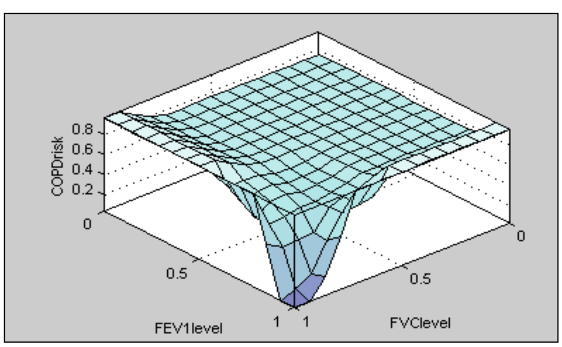

Fig. 4 Result of the simulation for COPDrisk

TABLE II
SIMULATION FOR "COPDrisk" RESULTS WITHIN %3 CONFIDENCE LIMITS FOR MALE VOLUTEERS.

FEV1 level	% COPDrisk			
	FVC =1	FVC = 0.99	FVC = 0.98	FVC = 0.97
0.5	96.2	96.1	96	95.8
0.6	95.7	82	85.9	72
0.7	95.6	82	85	71.1
0.8	94	83.9	85.6	72.3
0.85	9.54	8.32	8.6	72.1
0.86	4.62	4.65	7.6	4.45
0.87	3.13	3.34	3.5	3.46
0.88	1.87	1.86	1.83	1.79
0.89	1.65	1.65	1.64	1.16
0.90	0.39	0.61	0.78	0.94
0.91	0.4	0.63	0.78	0.94
0.92	0.4	0.68	0.84	0.9
0.93	0.4	0.68	0.84	0.9
0.94	0.4	0.63	0.78	0.8
0.95	0.39	0.39	0.4	0.42
0.96	0.38	0.39	0.4	0.42
0.97	0.38	0.39	0.4	0.42
0.98	0.38	0.39	0.4	0.42
0.99	0.38	0.39	0.4	0.42
1.00	0.38	0.39	0.4	0.42

According to this approach [9, 10], membership functions for each label assigned. For such a diagnosis system (Fig.1) with two inputs FVC & FEV1 levels, a rulebase and a "mamdami defuzzification module" defined to design an expert system as seen in Fig. 2 and Fig 3 [8-10].

E. Simulation

By embedding membership functions defined for each for input variables FVC & FEV1, and as an output variable, COPDrisk is defined with necessary membership function [9, 11]. By using the rulebase defined, and mamdami defuzzification, the simulation performed for "COPDrisk Percentage" results for normalized FEV1 values within %3 confidence limits of the normal cases for different normalized FVC values for healthy man is seen in TABLE II [9-15, 20-22].

After execution of the diagnosing program designed as an expert system [7, 9] used to categorize the spirometric FVC plots for the volunteer students. As an example, for a volunteer student with "VeryHigh" COPD symptom (acute bronchitis), the simulation result and the execution all of the rules presented in Fig. 3, after the treatment FVC and FEV1 levels measured gave the result "COPDrisk" as "High" [9]. The numerical result for the full-range simulation for FVC and FEV1 obtained as 3-D graph plotted by this program.

III. RESULTS AND DISCUSSIONS

As a mathematical conclusion or fuzzy logic approach, this study proves that fuzzy logic can be used in categorizing spirometric FVC graphs with high levels of confidence and, the best fitted curves defined for the FVC plots of spirometry used [9] are highly accurate to investigate the relationship between the characteristic constants of these best fitted curves and the degree of the disease, and the FEV1 measures for the subjects under test.

In this study, FVC graphs categorized with respect to "degree of COPD" by fuzzy logic. Additionally, FEV1 and FEV1/FVC ratio is used as important criteria to define each rule for the rulebase that is implemented for core of a COPD diagnosis program for clinical investigation.

High number of FVC graphs and corresponding FEV1 measures helped to define more accurate rules. Because, the accuracy of the membership functions for each fuzzy variable depend on the number of data collected, statistically.

Recommendations of Further Research

In the next studies, effect of questionnaire filled in by each subject on the result of the diagnosing (categorizing FVC graphs) COPD, elimination of erroneous factors affecting the results and, narrowing the confidence interval will be investigated to get more accurate results.

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